LST-R: A method for assessing land surface temperature reduction in urban, hot and semi-arid Global South

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Method Article

LST-R: A method for assessing land surface temperature reduction in urban, hot and semi-arid Global South

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ABSTRACT

Over the next 30 years, temperatures are expected to increase in hot semi-arid zones. Despite increasing studies on urban heat, cooling measures suitable for this climate zone remain poorly investigated. The proposed method is innovative because it focuses on significant landscape metrics for determining the land surface temperature (LST) and evaluating cooling measures. Recurrence of warm spells was identified analysing the daily air temperatures. Daytime and night-time LST data acquired from space were correlated with landscape metrics extracted from very high-resolution satellite imagery. Stepwise linear regression was used to identify the significant metrics that affected it. Cooling measures were selected considering implementation leeway; performance of existing measures; strengths, weaknesses, opportunities, and threats, equity analyses. Although the method was tested in Niamey, Niger, it can be applied to any city or town in hot semi-arid Global South, requiring decision-making support on cooling policies.

- Landscape metrics are consistent with development standard and general requirements.
- Evaluation of measures to reduce land surface temperature includes experts' advice.
- Equity of measures to reduce land surface temperature is considered.

Specifications table

Subject area:	*Engineering*
More specific subject area:	*Urban Heat Reduction*
Method name:	LST-R: Land surface temperature reduction in urban Global South
Name and reference of original method:	*Local climate zones; Land surface temperature – land cover change relationship by concentric rings*
Resource availability:	Warm spells: National directorate for meteorology of Niger Land surface temperature: ECOSTRESS data and Landsat land surface temperature tool, http://rslab.gr/landsat_lst.html Landscape metrics: Google Earth Pro-May 2020 Cooling measures SWOT: Expert survey Informal settlements: Google Earth Pro-May 2020 Tree-lined roads and green patches: Google Earth Pro-May 2020 Schools: http://umap.openstreetmap.fr/es/map/etablissements-scolaires-de-niameyniger_105887#11/13.5546/2.5200

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Introduction

High urban temperatures increase mortality, heat-related diseases, electricity consumption, and water demand [1–4], particularly in hot and semi-arid zones [5]. An urban-rural temperature gradient can detect an urban heat island. However, the temperatures differ within the built-up areas. Land surface temperature (LST) is the preferred parameter for studying this issue because it is measured over the entire area of interest and not just at a few points or along transects, as provided by meteorological stations or by temperature sensors and data loggers installed on vehicles. Local climate zones (LCZ) have been developed to study urban landscape–LST relationships [6]. Each zone identifies a homogeneous unit for geometric, land cover, thermal, radiative, and terrain roughness properties [7]. More recently, the landscape–LST relationship was investigated for concentric rings with a fixed pitch drawn from the city centre towards the outskirts. Within each ring indicators of complexity and form, such as patch density and mean area, fractal dimension, aggregation of impervious surfaces, and green spaces were related to mean LST [8,9].

LST assessments using these methods have proposed generic greening, increasing pervious surfaces, and built-up edge containment without providing practical guidance to decision-makers. Significant LST metrics should be identified, and specific measures reviewed in the literature to determine whether they fit the urban context under consideration, should be selected [10].

The LST reduction (LST-R) method assesses (i) air temperature dynamics; (ii) LST and landscape dynamics; (iii) significant landscape metrics in determining LST; and (iv) leeway of cooling measures, strength, weaknesses, opportunities, and threats (SWOT), and equity analyses to support decision-making on cooling policies (Fig. 1). The LST-R is exemplified by referring to Niamey, the capital city of Niger (217 km^2, with an estimated 1.2 million population in 2017).

Air temperature and warm spells

LST-R should be performed in hot, semi-arid zones during diurnal and nocturnal warm spells. The period was identified by processing daily maximum and minimum temperatures provided by the local meteorological organisation or by the National Oceanic and Atmospheric Administration (NOAA) website [11]. We analysed 40 years of daily maximum and minimum air temperatures at Niamey airport observed by Niger's National Directorate of Meteorology. Warm spells indicate the severity of heat over time. The duration and frequency of nocturnal warm spells were determined by using the same dataset. The warm spell duration index indicates the total number of days per year when the maximum temperature is higher than the 90th percentile of the reference period (1980–2020) for at least three consecutive days [12]. In Niamey, the diurnal 90th percentile is 43.9 °C and that of nocturnal is 31 °C. Diurnal warm spells were more frequent in the first 10 days of May and nocturnal warm spells were more frequent in the second 10 days of April (Figs. 2, 3).

LST data can be searched for after establishing the period of most frequent warm spells. Since 2018, ECOSTRESS data retrieved by the International Space Station, with a higher spatial resolution than that of Landsat data (70 m vs. 100 m), have been available. LST data should be sought when dust and cloud cover are absent and warm spells are more frequent. These conditions were satisfied on 2 May 2020, 11:45 am, and on 6 May 2020, 11:30 pm (Fig. 4).

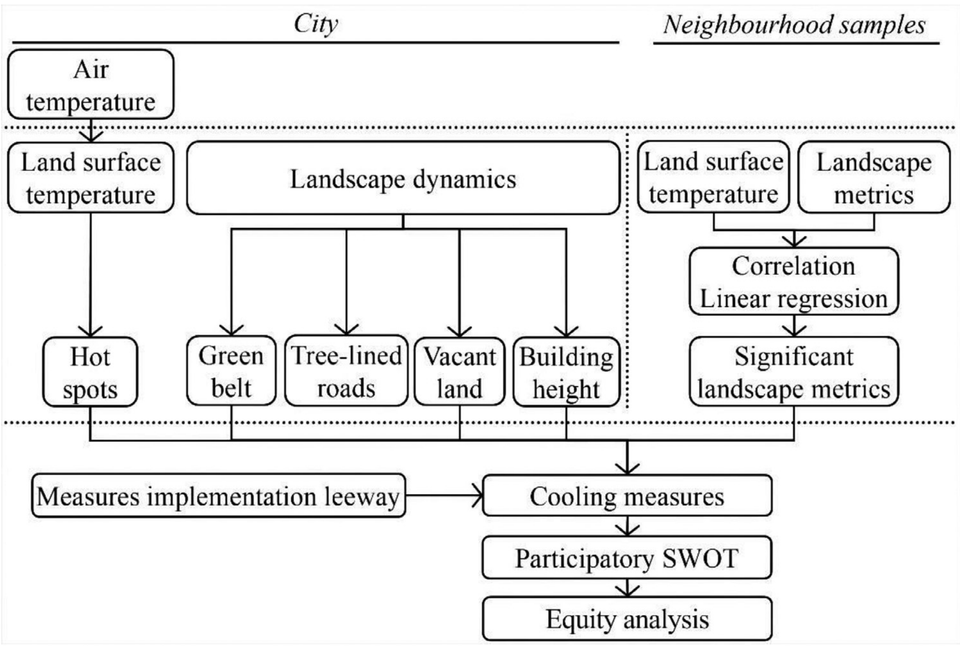

Fig. 1. Steps in LST-R.

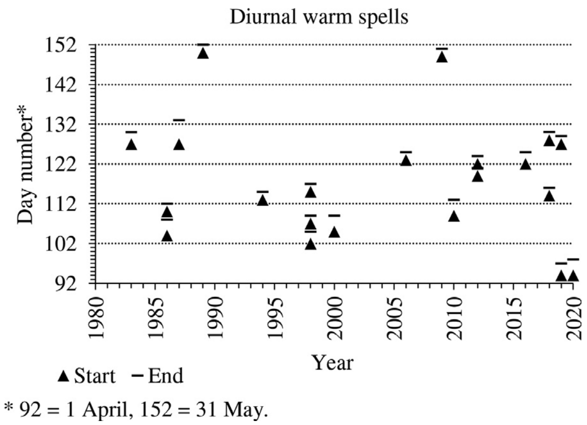

Fig. 2. Diurnal warm spell duration index (43.9 °C for 3 or more consecutive days) in Niamey, April–May 1980–2020.

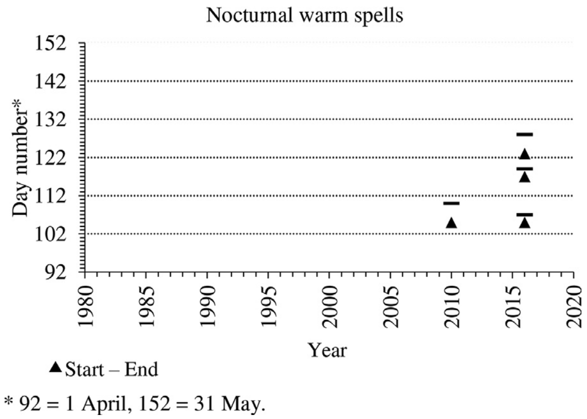

Fig. 3. Nocturnal warm spell duration index (31 °C for three or more consecutive days) in Niamey, April–May 1980–2020.

LST and landscape dynamics

The preliminary analysis of LST and landscape changes over the desired urban area helps identify cooling measures. To date, ECOSTRESS data allow such observations over a maximum time span of five years. Longer periods can be observed with Landsat-based LST data, exploiting different access points, e.g., the RS Lab (http://rslab.gr/landsat_lst.html) offering LST products resampled at 30 m resolution [13] (Fig. 5).

Large green patches, tree-lined roads, market gardens, paddy fields, vacant lots, and building heights were identified as the six landscape elements forming the existing resources and obstacles for reducing urban LST. Parks reduce urban heat in other climatic zones [14]. In hot, semi-arid Niamey, a green belt was created in 1965 across a 23.3 km^2 area to protect the city from dust winds [15]. Over time, the green belt was progressively cut down illegally. In 2002, it had decreased to 12.5 km^2. Although it was declared a public utility in 2011, the green belt is now reduced to 2.5 km^2 with an average of 40 trees per hectare under water stress, having grown on dry, bare soil. Canopy foliage temperature increases in dry sites, after prolonged drought [16] and when trees are surrounded by bare soil [17], explaining why the green belt is a hotspot in April and May. Isolated trees are the most common landscape along roads. Street trees were promoted during the presidency of Seyni Kountché (1974–1987) and only occasionally by subsequent governments. Presently, tree-lined roads are scattered and are only along path of 32 km (Fig. 6).

Market gardening has expanded in the last 20 years following urbanisation. Paddy fields created in the 1970s along the river are now incorporated into built-up areas. The role of vegetated areas in reducing urban heat through evapotranspiration has been proven in other climatic zones [18,19].

No vacant land was available within the consolidated city to create green patches. In the last 20 years, Niamey has expanded both horizontally and vertically. This change urges the understanding of materials and colours used in building envelopes that can increase solar radiation reflectance and reduce LST (Table 1).

Metrics significant to the landscape

Cooling measures to reduce LST are effective when landscape metrics are taken into consideration. In the absence of freely accessible geodatabases, metrics can be extracted from the visual photointerpretation of urban landscapes using very high-resolution (VHR) satellite imagery. In Niamey, the size of urban area and time required to measure landscape metrics suggest the use of samples

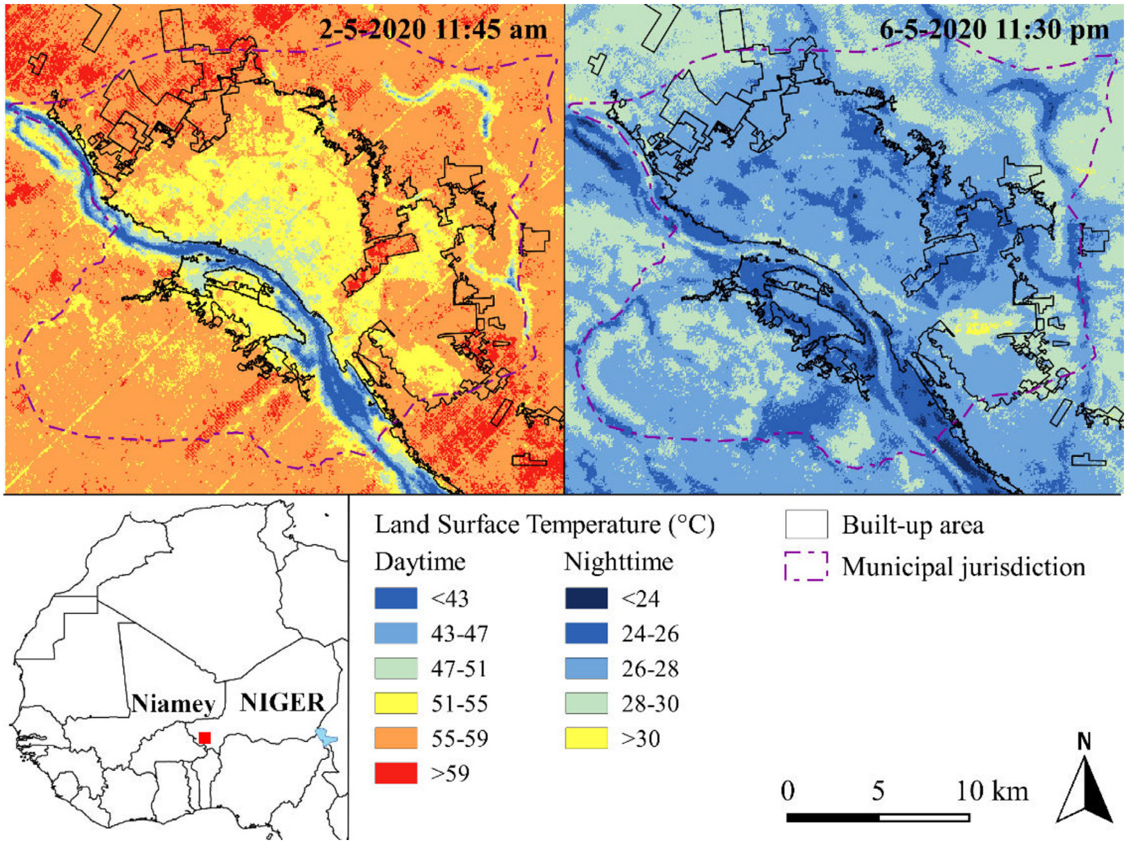

Fig. 4. ECOSTRESS diurnal and nocturnal images from Niamey on 2 and 6 May 2020.

Table 1
Long-term LST and landscape dynamics relevant for cooling measures identification.

Landscape element	Observed change	Measures implications
Day & night-time LST	Market gardening and paddy fields have the lowest LST	
	Green belt has the highest LST	Market gardening (horticulture for sale) policy
Green belt	Development and degradation	
Tree-lined roads	Limited to 32 km	Much space is available to increase street trees
Vacant lands	Development	Lack of areas for green patches creation
Building height	Increase across the city	Maximum height and building envelope requirements

for assessment. We considered 29 homogeneous landscape samples originating from a single land subdivision plan agreed between landowners and municipality. The area of each consolidated neighbourhood sample is 0.15 km^2 (Fig. 7). The average daytime and night-time LST for each sample were then extracted from the ECOSTRESS data (Fig. 8). Solar radiation reflectance depends on landscape material. Some tree species and soils in Niamey [15,20] resemble those reported in the ECOSTRESS library [21]. The average thermal infrared reflectances of library materials are listed in Table 2.

Tree cover, bare land, and unpaved and paved roads have low reflectance, whereas Al roofing has high reflectance. Moreover, the ECOSTRESS sensor acquired data in push-whisk mode (https://ecostress.jpl.nasa.gov/faq) with scan angles ranging from −25° to +25° (https://ecostress.jpl.nasa.gov/instrument): the radiometer scan was perpendicular to the ISS velocity (https://ecostress.jpl.nasa.gov/mission). Therefore, depending on the actual sun elevation, azimuth, and ISS position at the time/date of image acquisition, each ECOSTRESS pixel includes variable percentages of land cover types, lots, building walls, and shadows. The estimated LST value was influenced accordingly. This information is relevant for understanding the limitations of the method and identifying measures to reduce LST.

The 2020 VHR satellite images freely accessible on Google Earth (GE) Pro allow the extraction of shading, road width, bare land, unpaved and paved roads, roofs, and tree cover information through computer-aided photointerpretation, whereas the 2020 Sentinel-2 enables the extraction of shrub cover information at lower spatial resolution but uses semi-automatic classification algorithms (Fig. 9).

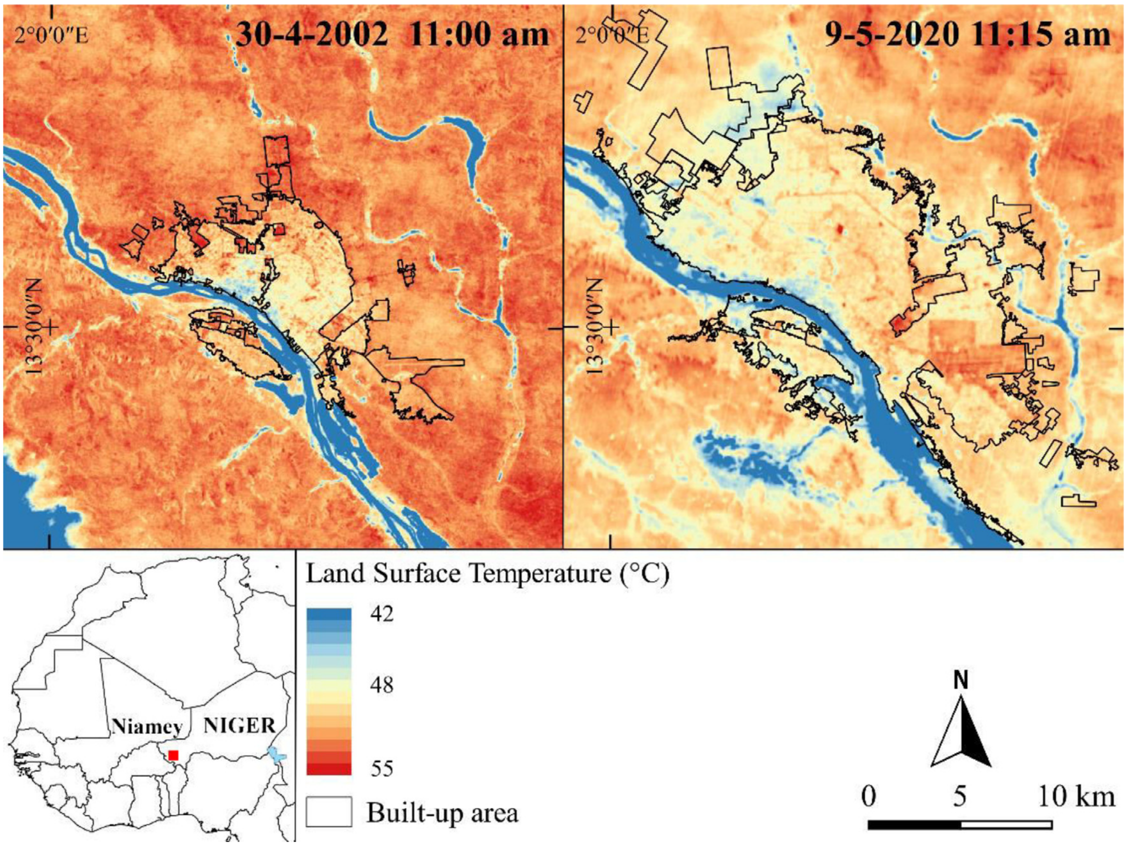

Fig. 5. LST from Landsat data, Niamey, on 30 April 2002 and 9 May 2020.

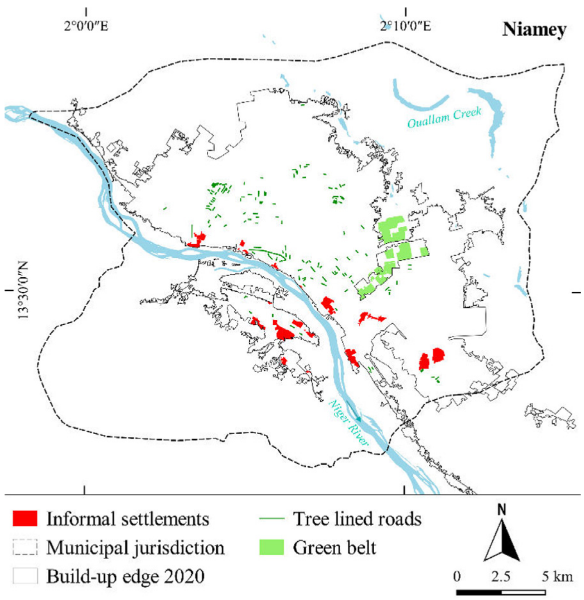

Fig. 6. Tree-lined roads, green belt, and informal settlements in Niamey on Mai 2020.

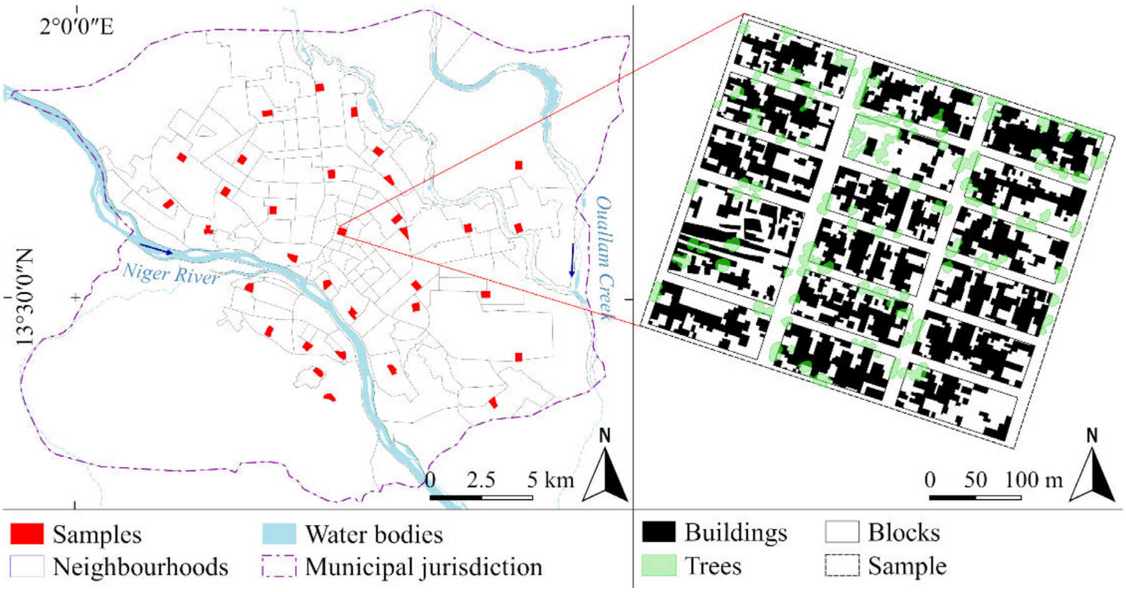

Fig. 7. Niamey district samples (left) and Boukoki neighbourhood sample (right) in May 2020.

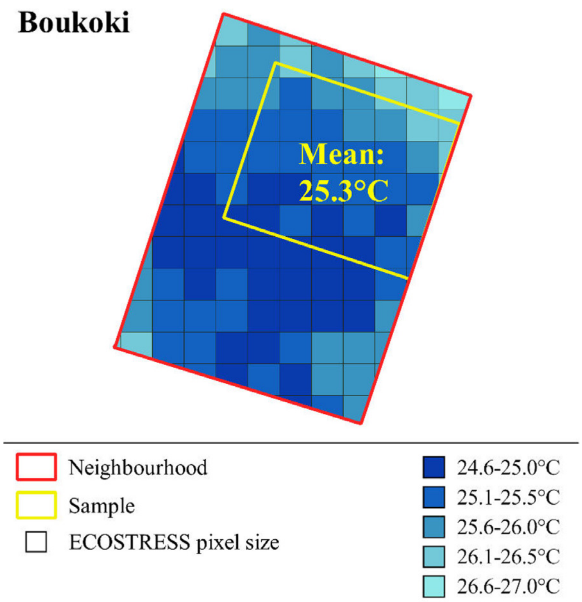

Fig. 8. ECOSTRESS pixels providing LST data for the Boukoki neighbourhood sample on 6 May 2022, 11:30 pm.

A shading analysis was carried out on a standard 20 × 20 m plot without trees enclosed by a 2.4 m high wall and with a 10 × 12 m and 3.5 m high building on it. The model was orientated N-S and then rotated to represent the 12 prevailing street orientations observed in the 29 neighbourhood samples. The shadow can be simulated and measured using SketchUp Pro 2021, in accordance with the city's geographical location and date/time of the space image. Here, the shadow varied in the range of 8–10% of the sample area (Fig. 10).

Road width is the average value obtained by weighting the width of each road in the sample by its length. This metric is recognised as a driver of LST in hot, semi-arid climates [22], and varies between 5 and 26 m.

Bare land is the remaining area after subtracting the area covered by roofs, trees, and shrubs, which is 59–89%.

Paved and unpaved roads occupy 0–7% and 18–63% sample area, respectively.

Roof cover is important because it uses materials with high reflectance (Table 2). The proportion of sample area varied from 9% to 59%.

Table 2
Average thermal infrared reflectance (8–12 µm) for 13 landscape materials, and to Niamey equivalents.

Landscape material		Average reflectance of materials in the ECOSTRESS library %
ECOSTRESS library	Niamey equivalent	
Water		1
Grey rey grass		2
Acacia visco	Acacia Senegal	2
Grey-white concrete pavement		3
Cassia Lepthophilla		4
Eucalyptus maculate	Eucalyptus camaldolensis	4
Entisol soils	South riverbanks	4
Asphalt		5
Haplustalf soils	Built-up, expansion area	6
Cement block		6
Window glass		17
Oxidised steel roof		22
Aluminium roof		95

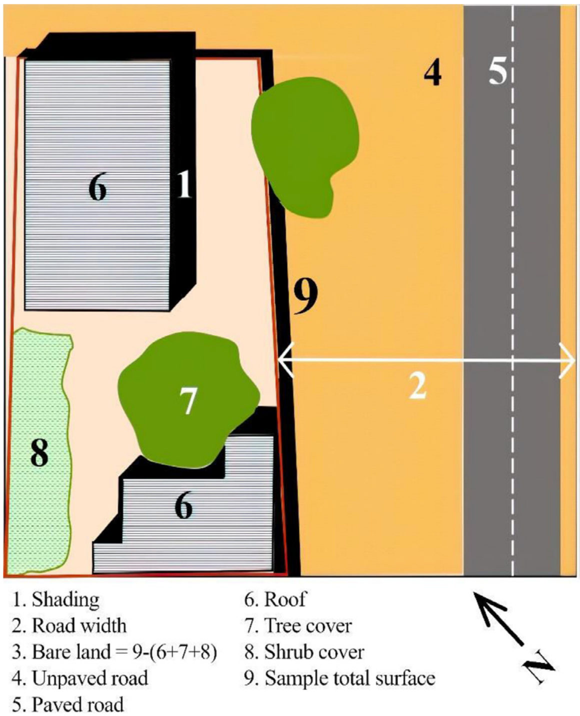

Fig. 9. Landscape metrics.

Tree cover lowers the air temperature under the tree canopy in hot arid climates [23]. It was derived using visual photointerpretation of VHR satellite images, as it better highlighted the differences between Normalized Difference Vegetation Index (NDVI) samples than Landsat and Sentinel data.

Shrub cover, believed to lower the LST, was extracted from the worldwide land cover mapping produced by the European Space Agency using Sentinel-1 and 2 from 2020 images with a ground resolution of 10 m [24]. The range is 0–45%.

The landscape metrics and correlated diurnal and nocturnal LST (Table A1) for each neighbourhood sample showed that tree cover lowered diurnal LST (correlation of –0.76). A similar effect was observed for roofs (–0.41). By contrast, bare land increased diurnal LST (0.71), while paved roads, tree cover, and road width contributed to nocturnal LST (0.60, 0.55, and 0.36, respectively) (Tables 3, 4).

Stepwise linear regression analysis [25] showed the statistical significance of landscape metrics highlighted by a previous correlation analysis of diurnal and nocturnal LST.

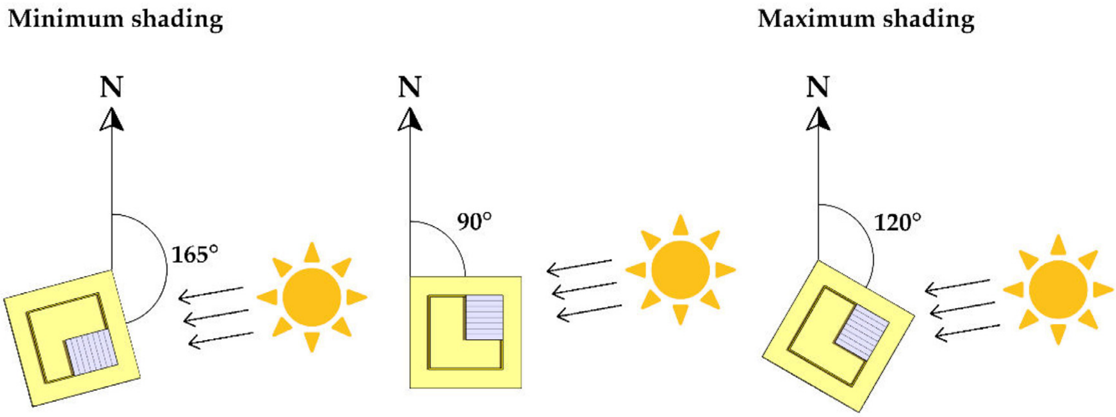

Fig. 10. Standard lot shading on 2 May, 11:45 am in 3 most frequent street orientations found in the neighbourhood samples.

Table 3
Landscape–LST correlation in Niamey in May 2020.

Landscape metric		Average	Range	Landscape–LST correlation	
				Diurnal	Nocturnal
Diurnal LST	°C	52.8	9.8		
Nocturnal LST	°C	26.3	3.2		
Shading	%	9.2	2.0	−0.24	0.14
Road width	m	14.3	21.0	0.06	0.36
Bare land	%	66.1	91.0	0.71	−0.41
Unpaved road	%	32.9	45.0	0.35	0.21
Paved road	%	0.9	7.0	−0.36	0.60
Roof	%	24.4	33.0	−0.41	0.17
Tree cover	%	9.1	38.0	−0.76	0.55
Shrub cover	%	0.4	6.0	−0.03	−0.15

Table 4
Correlation matrix between dependant and independent variables.

Variables	Day LST	Night LST	Shading	Road width	Bare land	Unpaved road	Paved road	Roof	Tree cover	Shrub cover
Day LST	1									
Night LST	−0.26	1								
Shading	−0.24	0.14	1							
Road width	0.05	0.36	−0.03	1						
Bare land	0.70	−0.41	−0.22	−0.06	1					
Unpaved road	0.35	0.21	−0.15	0.45	0.29	1				
Paved road	−0.35	0.60	0.19	0.39	−0.26	0.46	1			
Roof	−0.40	0.17	0.13	−0.22	−0.85	−0.33	−0.05	1		
Tree cover	−0.75	0.55	0.21	0.34	−0.82	−0.13	0.52	0.41	1	
Shrub cover	−0.03	−0.15	0.07	0.02	0.32	−0.06	−0.16	−0.39	−0.28	1

R-squared (0.751) denotes the overall fair capability of the significant metrics to capture the variability in the collected data. The results show a 0.12 °C increase in diurnal LST for each 1% increase in street width. That is, a tree canopy covering a 10-m-wide strip on roads that are at least 18 m wide would reduce the LST of each sample by 6 °C (Table 5).

The opposite effect was observed for tree and shrub cover. There was no shrub cover (i.e., their values were equal to zero) in 24 of the 29 landscape samples considered in this analysis. However, Table 5 shows that only five non–null entries for this variable make it significant (P-value = 0.003725) in the regression analysis. This suggests that shrub cover is a crucial variable for reducing the LST. We concluded that the introduction of even a small portion of this landscape metric led to a reduction in LST.

A second quantitative investigation was performed by setting quartile (Q) thresholds and excluding regression observations below or above these values (Table 6).

It is well known that quartiles are robust statistics in descriptive analysis and allow for the identification of possible outliers in the observed data. Using quartiles as objective thresholds provides a way to exclude observations that might lead to misleading regression analyses. The quartiles displayed in Table 6 were determined by considering the full available dataset.

Because only five samples had shrub cover greater than 0, this metric was excluded from the threshold analysis. Removing road width observations that were less than the first quartile, produced interesting results (Table 7).

Table 5
Stepwise linear regression. Diurnal LST (dependant variable), road width, tree, and shrub cover (independent variables), 0.751 adjusted R-squared, 29 observations.

Landscape metric	Estimate	*P*-value
Intercept	53.255	4.4293e-36
Road width	0.12133	0.000528
Tree cover	−0.21544	1.2644e-09
Shrub cover	−0.41161	0.003725

Table 6
Quartiles for significant landscape metrics.

Quartile	Road width	Tree cover	Shrub cover
First	11	4	0
Median	14	7	0
Third	18	11	0

Table 7
Stepwise linear regression results – diurnal LST (dependant variable), road width, tree, and shrub cover (independent variable). Road width lower threshold 11 m adjusted R-squared 0.817, 22 observations.

Landscape metric	Estimate	*P*-value
Intercept	53.064	9.2508e-25
Road width	0.13131	0.004207
Tree cover	−0.21492	1.1967e-08
Shrub cover	−0.40198	0.0035595

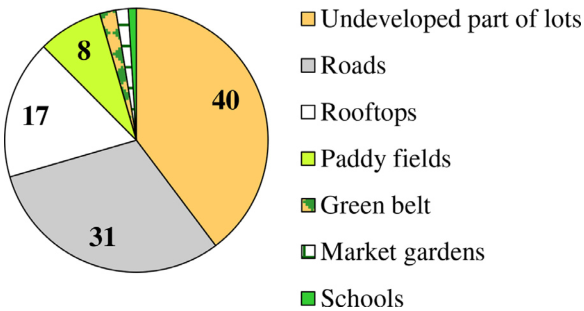

Fig. 11. Land cover in Niamey, May 2020.

The regression estimates in Table 7 are very close to those in Table 5 but shows improved adjusted R-squared value (normal probability plot of residuals for these regressions in Table 4).

As the estimate for road width was positive, the larger the roads the larger their impact on higher diurnal LST. This result can be coupled with the fact that, when observations with large road width values were excluded, which form the third quartile (18 m), the adjusted R-squares decrease to 0.62 during the regression analysis. These observations led to the nonlinearity of the impact of road width on diurnal LST, and the negative impact of larger roads. Unfortunately, no improvement in terms of goodness of fit was detected when the thresholds were applied to trees.

The next step was to identify measures that can modify the three significant metrics to generate a cooling effect.

Leeway of cooling measures, SWOT, and equity

The identification of measures to reduce LST should consider the existing leeway provided by undeveloped areas such as lots, roads, roofs, paddy fields, large green areas, market gardens, and schools, which corresponded to 40, 31, 17, 8, 2, 2, and 1% respectively, in Niamey (Fig. 11).

Given the difficulty in regulating the already developed private properties, the leeway to implement cooling measures is provided by roads and schools. An increase in tree cover should be implemented along roads and school limits. These measures should allow for a clear reference that all inhabitants can see and appreciate. Tree-lined planting along roads is effective [26] if the canopies exceed the buildings height [27]. In Niamey, they extend over 32 km (Fig. 6). Trees were planted along the school lot edge, for example, at

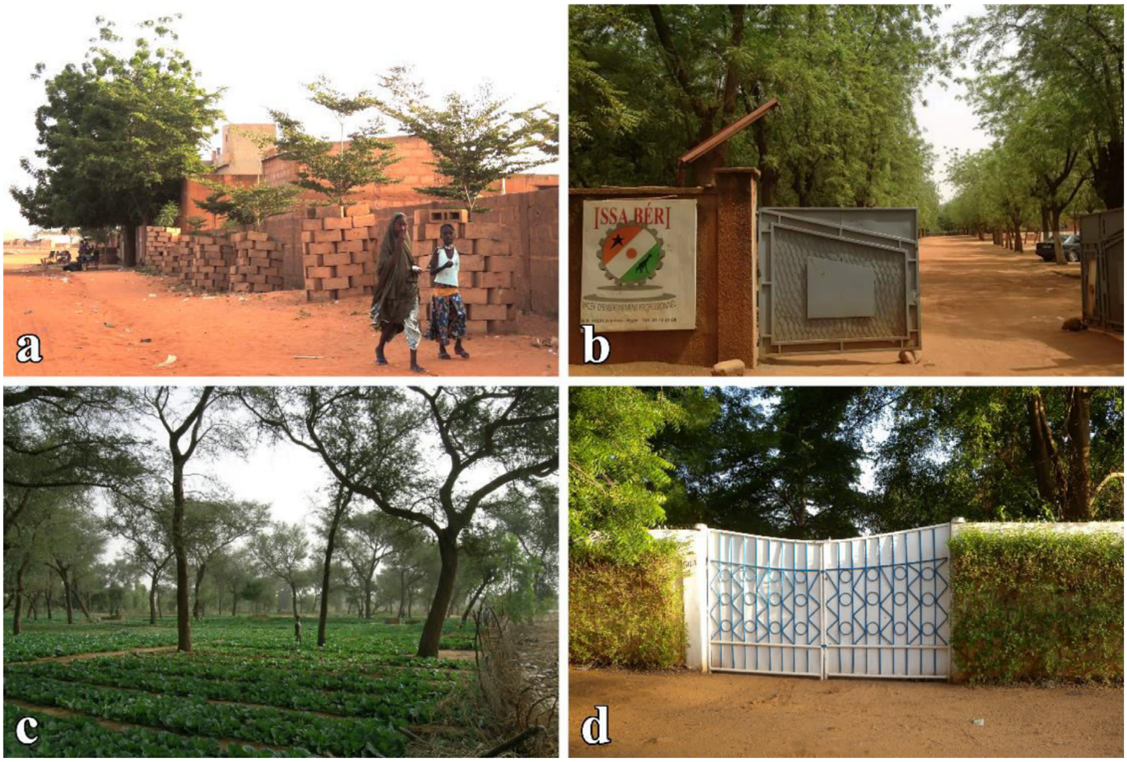

Fig. 12. Tree-lined road (a) Issa Béri school tree edges (b), agroforestry (c), green lot edge (d) in Niamey by M. Tiepolo (a, c, d) and [29] (b).

Table 8
Cooling measures for Niamey.

Cooling measures	Landscape significant metrics		
	Street width	Tree cover	Shrub cover
Findings	• Wide bare strips of land along roads	• Few tree-lined roads • Canopy foliage is warmer when trees are isolated on dry soils and cooler when trees grow on moist soils [16,17]	• Rare use of thorny vegetation to cover the perimeter wall of plots
Implications	• Lined trees along 18 m wider roads	• Tree integration in gardening and paddy fields • Tree planting along school lot edge	• Green lot edge requirement for new developments

the Issa Béri school (Fig. 12). Agroforestry on moist soils [16,17] has been practiced in some market gardens (Fig. 12). Living walls have proven effective in reducing heat in hot, semi-arid environments [28]. In addition, the green lot edge was pioneered for some properties (Fig. 12, Table 8).

The suitability of the measures identified to form part of a cooling policy should be assessed by participated SWOT analysis, with representatives from the municipality, ministries, grassroot organisations, and local scholars. In Niamey, the pandemic forced the replacement of this step with an expert survey of the four identified measures. Experts from various disciplines were identified to obtain a more comprehensive picture [30]. The invitation letter was mailed. We received 16 responses from representatives of ministries, NGOs, associations and scholars from local university and research institutes (Table 9).

Tree-lined roads can reduce LST by 0.12 °C for every 1% narrowing of road width. Forestations can take several years to produce the expected shading effect. Moreover, it offers a favourable environment for mosquito proliferation, which requires seasonal pest control of the foliage.

The opportunities for such developments lie with national NGOs that are active in urban forestry. Official development aid (e.g., The Great Green Wall initiative), government programs (Green and Fruit City), and the annual tree festival celebrated on national independence day can provide tree planting opportunities.

The main threats are a lack of funding, occasional droughts, and the high, ever-increasing price of water, which hinder the poor from greening their outdoor spaces.

Table 9
SWOT of cooling measures for Niamey, March 2022.

Cooling measures	Strengths	Weaknesses
Tree-lined roads	• City beautification • Equitable shading • Soil fixation • Games can be played in the shade • Road width reduction is linked to LST • Beneficial for pedestrians • Carbon sinks	• Lack of maintenance • Choice of plant species • Unfit narrow streets, small lots • Informal activities along the roadside • Unauthorised cutting of trees • Wandering animals eating unprotected young trees • Lack of appropriation by neighbours • Increase in mosquito • Need for irrigation after tree taming • Lack of regulation to avoid river and creek banks development
Tree-lined school edge	• Pedagogic implications • Shadow for ludic activities	
Agroforestry	• Upper canopy of tree on moist soils is cooler during day and night	• Lack of space when market gardens are small
Green lot edge		• Unaffordable for the Poor [31] • Difficult to impose on private property
	Opportunities	Threats
Tree-lined roads and school edge	• Youth, students, grassroot organisations; NGOs, neighbours • Enterprise social responsibility • The Great Green Wall initiative [32] • World Bank programs • Tree festival • Green and fruit city program	• Lack of financial resources • Drought
Green lot edge	• None	• High water prices

The LST-R is accomplished using location, quantification, and equity of measures [33–35]. The mapping of roads by width, if they do not already exist in the municipal geodatabase, can be derived from the VHR satellite imagery accessible from GE Pro. The street grid superimposed on neighbourhood boundaries, especially informal settlements, allows analysis of the equitable distribution of tree-lined roads.

In Niamey, roads over 18 m wide impacted LST negatively, but that width facilitated planting a row of trees that can shade the ground and surrounding buildings during the daytime and lower night-time LST (Fig. 13).

The analysis showed that 89 out of 98 neighbourhoods had streets more than 18 m wide. Thus, planting trees equivalent to 60% of those currently existing in the green belt in the form of street trees would benefit 89 neighbourhoods while adding the same amount to renew the green belt would benefit only the 10 neighbourhoods surrounding it (Fig. 6).

The location of market gardens highlights their cooling potential in nearby neighbourhoods. This is also possible through VHR satellite imagery, which is freely accessible from GE Pro (Fig. 13). In Niamey the location of market gardens cools the neighbourhoods along the river and in the northeast direction towards Filingué, and the central neighbourhoods crossed by the Gounti Yena creek.

The school locations were provided by the Ministry of National Education or can also be obtained from an open street map (Fig. 13). In Niamey, their distribution [36] is widespread in consolidated neighbourhoods, that are close to informal settlements. Schools have an average of 68% lot edge without trees. Therefore, greening offers multiple benefits for educational activities and close surroundings [37]. The lined trees amount to approximately 57,600 if planted one tree every 10 m on one side of the road and 58,200 trees if planted on both sides, where roads exceed 36 m in width. The stock distribution for roads and schools was 91% for and 9% respectively. Additionally, 3.4 km^2 of market gardens should be partially planted (Table 10). These would be modest cost measures achievable in a short time if they were allocated to a team equipped with vehicles and a tree nursery in each city district. More important are the costs of protection and maintenance (watering, protection, pruning, pest control) and involving the residents. These measures would increase tree-lined roads from the current 32 km to 523 km and distribute greening more equitably than the current 2.4 km^2 of the green belt (Fig. 14).

Method limits

First, LST-R considered only the landscape metrics measured from the VHR satellite imagery. The roof and wall materials exhibited a wide range of reflectance values (Table 2). These affect each ECOSTRESS pixel. However, these materials cannot be identified with

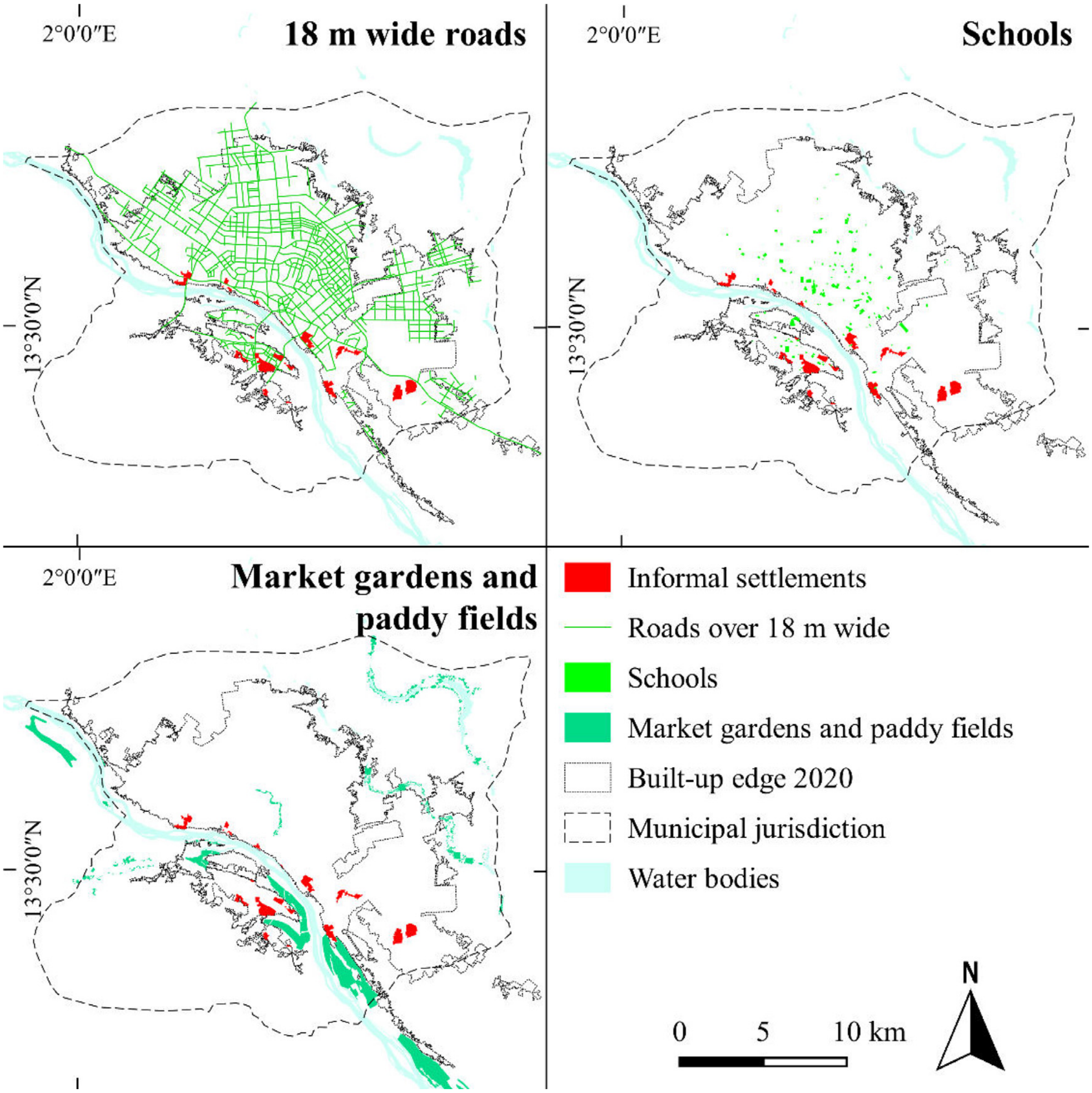

Fig. 13. Cooling measures and informal settlements in Niamey in May 2020.

Table 10
Tree planting to reduce LST in Niamey.

Location	Tree planting needs	
	Length Km	Surface Km^2
Roads 18 m wider	523	–
Market gardens	–	3.4
School lot edge*	53	–
Total	576	3.4

*139 schools.

certainty in the VHR images. Hence, recommendations for envelope materials have not been made yet. Second, samples from industrial and administrative areas were excluded. However, the latter constituted only a small share of the total urban area.

Third, the 10 m distance between trees used to assess planting needs for creating tree-lined roads should be verified because in warm-temperate climate a cooling effect of tree cover was observed at distances up to 50% of the crown radius [38].

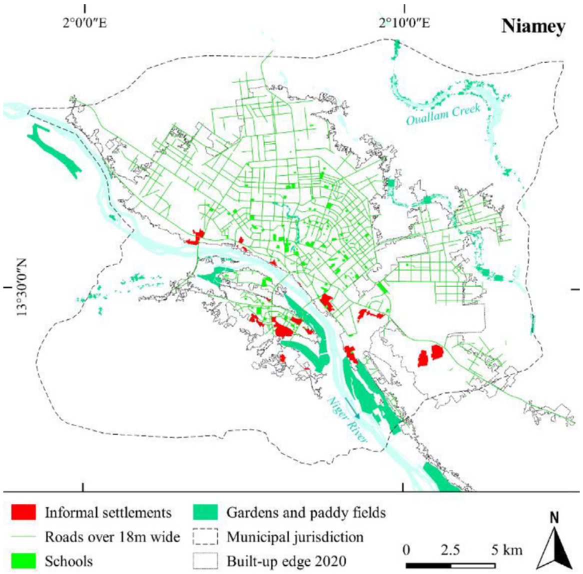

Fig. 14. Roads over 18 m wide, schools, market gardening and paddy fields in Niamey on May 2020.

Fourth, the assessment did not consider tree species taking root quickly, requiring less care, and having a larger crown for shading [15] and foliage density [39].

Finally, planting along the lot edges should be carried out for each ministry, public body, and local government department that occupies large plots, the locations of which are only partially known at the time of assessment.

Conclusion

The LST-R integrates existing methods to analyse LST with the following two novelties: (i) considering landscape metrics that are significant with respect to daytime and night-time LST, and (ii) participatory evaluation of SWOT and equity of cooling measures. LST-R, LCZ, and LST using concentric ring methods use different metrics to characterise the urban landscape. In hot and semi-arid zone, LST-R method highlighted the significance of road width, tree, and shrub cover in determining daytime LST and that of road width in determining night-time LST. The implication of these results on cooling policies is that tree-lined roads and tree–planting around school buildings is more suitable than greening private properties.

The method was applied in Niamey, Niger. Nevertheless, it can be replicated in other cities and towns in hot, semi-arid zone. In other climates, landscape metrics that are significant with respect to LST should be ascertained, and the consequent cooling measures should be identified and evaluated.

The assessment of LST-R for decision making on cooling policies should be set up within a participatory process and not in disciplinary isolation. The landscape metrics should be consistent with planning development standards and general requirements. This implies that from the beginning, LST reduction measures should be identified as the assessment objective. Then, the relationship between the landscape and LST would highlight the significant metrics and the measures to act on them would be clearly defined, which rarely happens in LST assessments.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in this study.

Data availability

Data will be made available on request.

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Appendix A

See Appendix Table A1

Table A1
Diurnal and Nocturnal LST (ECOSTRESS data) and landscape metrics in the 29 neighbourhoods' samples.

Neighbourhood	Sample surface (ha)	Diurnal mean LST (°C)	Nocturnal mean LST (°C)	Shading (%)	Road average width (m)	Bare land (ha)	Unpaved roads (ha)	Paved roads (ha)	Roofs (ha)	Tree cover (ha)	Shrub cover (ha)
Aviation	15	53.4	26.7	10	12	11.7	4.6	0.0	3.3	0.9	0.6
Baba Fandou	15.3	54.8	26.3	10	14	13.3	4.3	0.0	2.0	0.3	0.2
Banga Bana	15.4	53.6	25.5	10	9	11.2	4.5	0.0	4.2	1.1	1.1
Banifandou 2	15.2	52,6	26.9	10	16	10.5	6.9	0.2	4.7	1.6	2.2
Boukoki 1	15.6	52	25.3	10	14	9.7	4.2	0.1	5.9	1.5	2.0
Green belt	14.8	55.5	26.3	9	20	13.2	8.9	0.4	1.6	0.3	0.3
Green belt B	15.6	54.6	26.3	9	10	12.1	7.4	0.0	3.5	0.4	0.3
Filingue	15	53.8	27.3	9	25	11.7	7.6	1.1	3.3	1.6	1.8
Gamkallé	15.9	51.9	27.1	10	7	9.7	4.0	0.0	6.2	1.7	1.9
Goudel	15	52.5	26.5	10	5	9.6	2.7	0.0	5.4	1.2	1.2
Ida Gano	15	53.7	25.6	8	15	11.9	4.7	0.0	3.1	0.5	0.3
Kirkissoye	15.1	52.6	25.7	8	8	10.6	3.1	0.0	4.5	0.9	1.1
Koira Tegui	15.5	54.5	26.2	8	13	11.8	6.9	0.0	3.7	1.0	0.8
Koubia	14.9	55.0	27.1	8	15	12.2	4.4	0.0	2.7	0.6	0.5
Lamorde	15.4	52.3	26.4	8	17	11.2	4.5	0,0	4.2	2.0	2.3
Lazaret	14.9	52.4	26.4	8	15	10.2	4.6	0.0	4.7	1.3	1.3
Lesso Gourou	15.6	52.4	26.2	8	18	11.6	5.6	0.0	4.0	2.1	2.8
Nialga	15.3	50.6	25.5	8	8	12.0	4.7	0.0	3.3	1.0	1.8
Niamey 2000 ex	15.7	54.4	26.0	10	15	13.6	4.4	0.1	2.1	0.7	0.2
Plateau 1	16	48.4	27.7	10	24	13.0	4.2	0.8	3.0	6.1	7.3
Yantala resettle	14.5	53.0	26.3	10	26	8.6	4.1	0.0	5.9	2.3	3.5
Saga	15,3	53.2	25.9	10	6	11.1	4.0	0.0	4.2	1.4	2.0
Saga Fandou	15.9	53.1	25.3	10	12	11.7	4.9	0.0	4.2	1.2	0.6
Saguia	14.7	51.9	25.3	10	11	12.5	4.2	0.0	2.2	0.5	1.2
Sary Koubou NE	15	55.1	26.4	8	18	13.7	4.8	0.0	1.3	0.1	0.0
Sonuci Koubia	15.2	52.3	27.3	10	20	10.4	4.4	0.0	4.8	2.5	3.1
Talladjie	15	52.5	25.7	8	12	10.4	4.5	0.0	4.6	1.8	1.7
Terminus	15.3	49.2	27.8	10	11	10.3	3.8	1.0	5.0	3.4	6.2
Equipement	15.9	52.1	25.8	10	18	14.2	5.4	0.0	1.7	6.0	2.9

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